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Energy in Agriculture: Energy Resource Series for Youth and Adult Energy Programs: 2. Definitions

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AEES-22

ENERGY IN AGRICULTURE

Energy Resource Series for Youth and Adult Energy Programs

2. *Definitions*

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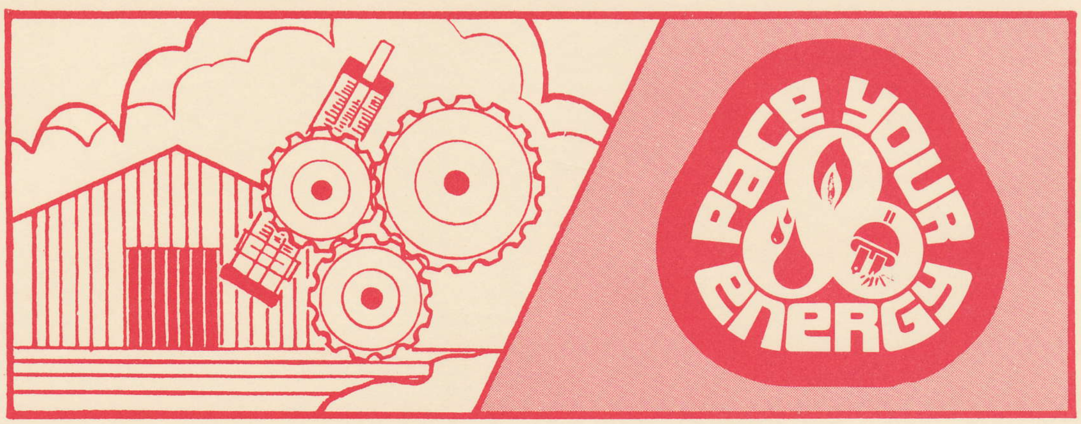

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Preface

The purpose of this publication is to define and/or describe technical words and concepts common to the subject of energy. Many words and terms relating to energy have a lengthy history attached to their evolvement to present day usage. Therefore, it is often impossible to completely define or adequately explain them in a concise statement or two. In these cases, several different approaches are used in describing them, so that you will fully understand these terms as used in most contexts.

In many cases an unfamiliar word or term will be used in describing another word. In most cases, this word or term will be described elsewhere in this publication. In all cases, the reader is urged to seek definitions and descriptions from other sources, such as textbooks on energy, physics, chemistry, biology and various encyclopedias.

This is the second publication in a 12-part energy resource series designed for adults and students with a serious interest in the energy situation. Each publication in the series examines a different energy source and considers the advantages and disadvantages associated with its use.

When necessary, diagrams and/or tables are used to clarify or elaborate upon information found in the text. Questions with answers are included at the end of each publication, so that you can test what you have learned.

The author wishes to thank Wiley Henson, Elmon Yoder and Linda Bach of the Department of Agricultural Engineering, University of Kentucky, for reviewing the text.

The Energy Resource Series for Youth and Adult Energy Programs includes the following publications:

AEES-21	Energy Overview
AEES-22	Definitions
AEES-23	Oil and Gas
AEES-24	Coal
AEES-25	Solar
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Introduction

The words described in this publication are used in the other publications in this energy resource series without further defining.

In most cases the first sentence, paragraph or formula describes a word or term sufficiently to use it. The added explanation is an attempt to give the reader a firm foundation for using the word confidently in energy programs.

Work

In mathematical terms: **Work = force x distance.** This formula is used universally to describe or calculate a quantity of work. For work to take place a force must exist. The force may be given in pounds (lb), grams (g) or tons, and this force must move something a distance, which may be given in miles (mi), feet (ft), meters (m) or centimeters (cm).

The name of the product obtained by multiplying the force by the distance consists of two words, one from the force list and one from the distance list. Any combination of the two can be used, but traditionally units from the metric and British systems of measurement are not mixed. Instead, the following combinations are those most commonly used: foot-pounds (ft-lb), gram-centimeters (g-cm) and kilogram-meters (kg-m).

Energy

Energy is the ability to do work. The terms energy and work mean the same thing. They both imply an activity or a force moving an object a certain distance.

Power

Power is the rate of doing work. Rate means doing something in a unit of time. The time unit can be one second (s), one minute (min), one hour (h) or one of any stated length of time. It is important to know that a unit means one. Many times the word each or per is used instead of unit or one.

In a mathematical formula:

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{\text{force x distance}}{\text{time}} = \frac{\text{F x D}}{\text{T}}$$

The words work and power are often interchanged in everyday conversation. Technically there is a world of difference between them. Suppose a small boy carries a 10-pound bucket of water up a hill, 50 feet high. He has raised the 10 pounds 50 feet. The work he did on the water was 10 x 50 or 50 ft-lb. Assume that a stop watch was used, and it is found that his time was 20 minutes.

Compare this with what his big brother could do. He could carry the 10-pound bucket up the same hill in 5 minutes. The big brother did the same quantity of work, 50 feet x 10 pounds or 500 ft-lb. However, the big brother did the same work in one-fourth the time. He had four times more power than his little brother.

Some simple arithmetic can illustrate the comparison. The small boy did the work in 20 minutes therefore:

$$\text{Power} = \frac{\text{F x D}}{\text{T}} = \frac{10 \text{ x } 50}{20} = 25 \text{ ft-lb/min}$$

The big boy did the work in 5 minutes therefore:

$$\text{Power} = \frac{\text{F x D}}{\text{T}} = \frac{10 \text{ x } 50}{5} = 100 \text{ ft-lb/min}$$

Notice that the answer for the big brother is four times as large as for the little boy. We can say that the big boy is four times as powerful as the small boy. It is very important to remember that the work each did is the same, only the time is different.

The units of power are usually as follows: foot-pounds per minute (ft-lb/min), gram-centimeter per second (g-cm/s) and kilogram-meter per second (kg-m/s).

Horsepower

The word horsepower (hp) is so frequently used that some effort will be taken to explain it. It is simply a comparison of any power to what a horse could do. If a person has a 3hp lawnmower, this actually means that this machine can do what three good horses could do in the same time.

Historically, when horses were used to haul materials from mines it was found that a good horse could hoist 150 pounds out of a mine along a distance of 220 feet in 1 minute. Soon owners of other horses took great pride in any of their horses that could equal this feat. This soon became the standard that was expected of good horses.

The work that a horse, or humans for that matter, accomplished was:

Work = force x distance = 150 lb x 220 ft = 33,000 ft-lb

It made no difference if a smaller horse took 5 minutes or a group of men pulled the load out in 20 minutes. The work done was the same, 33,000 ft-lb.

Because the standard had become this work done in 1 minute, the power of one horse was:

1 horsepower = 33,000 ft-lb/min

The comparative power of the small horse that did the work in 5 minutes was:

hp = 33,000 ft-lb/5 min = 6,600 ft-lb/min

This is one-fifth the work that a good horse could do in the same time; it was said that the small horse produced one-fifth of a horsepower, and the owner was paid one-fifth as much for the use of such horses.

If two men pulled the load out in 20 minutes, their comparative power was:

hp = 33,000 ft-lb/20 min = 1,650 ft-lb/min

Because two men did this work, the power of each was:

$$\frac{1{,}650}{2} = 825 \text{ ft-lb/min}$$

This is one-fortieth of what a good horse could do; it could be said that one man is equal to one-fortieth of a horsepower.

It should be pointed out that the workday in the mines back then probably lasted 10 or 12 hours. A fresh horse in the morning would probably pull the same load out much quicker. The same two men could probably quickly pull the load out once or twice but as the day wore on they would slow down. The figures used are the average power over the day rather than a peak output.

Suppose that a tractor has a recording scale attached to the drawbar, and it is found to pull with a force of 4,000 pounds. While pulling with this force it can travel a distance of 5,000 feet in 15 minutes. The question then is, what is the drawbar horsepower of the tractor?

$$\text{hp} = \frac{F \times D}{T} = \frac{4{,}000 \times 5{,}000}{15} = 20{,}000{,}000 \text{ ft-lb/15 min} = 1{,}333{,}333 \text{ ft-lb/min}$$

Now, if this is divided by the standard amount for 1 hp, the ratio is:

$$\frac{1{,}333{,}333 \text{ ft-lb/min}}{33{,}000 \text{ ft-lb/min}} = 40.4 \text{ hp}$$

This tractor will do 40 times what the standard good horse could do.

Horsepower Hour

The unit horsepowerhour (hph) is used in financial transactions. It is the quantity of power used for a given job. If a tractor were equipped with a hph meter, the quantity could be read directly and a charge per unit would suffice. For instance, if a 40 hp tractor pulled a constant load at a constant speed for a 10-hour day it would do 400 hph of work. If the rate was 20 cents per hph the total bill for the day would be $80.

Horsepowerhour meters on farm tractors are not common like the home electric power meter. Usually farm and industrial tractor custom rates are based on past experience for similar jobs.

Watt

A watt is a unit of electric power. This may be slightly harder to grasp than the description of mechanical power just given but if read carefully it can be understood.

$$\textbf{Remember that Power} = \frac{F \times D}{T}$$

The meaning of the word watt is arrived at like this. Electricity consists of moving electrons. One ampere (amp) of electricity is one package of electrons moved past a point on a circuit in 1 second of time. The package contains 628 x 10^{16} electrons and is therefore of definite size and is called a coulomb. Therefore, 1 amp = 628 x 10^{16} electrons/s. It takes a force to make the package of electrons move. This force is commonly called voltage but in physics and electricity books it is called an electromotive force, a very descriptive term. Work is done in an electric circuit when a package of electrons is forced to move a distance; therefore W = F x D just like mechanical work. The power of an electric circuit is calculated by how fast this work is done or:

$$\text{Watts} = \text{power} = \frac{\text{force x number of packages}}{\text{second}} =$$

$$\frac{\text{volts x coulombs}}{\text{second}} = \text{volts x amps}$$

or:

W = V x A

When an electric force of 1 volt will cause 1 amp to move through a circuit this quantity of power is called a watt. If it takes 10V to move 1 amp through another kind of circuit the power is:

1 amp x 10 volts = 10 watts

Another example. If 15 amps flow in a circuit with 110 volts of force, the power of the circuit is:

15 amp x 110 volts = 1,650 watts

Kilowatt Hour

Since most homes use many hundreds of watts of power per month, it is more convenient to use smaller numbers pertaining to larger packages; hence the kilowatt or a group of 1,000 watts in a package. Every home and business has a kilowatt-hour (kWh) meter, sometimes found in the basement, utility room or outside.

If a home is using electric energy at the rate of 15 kilowatts per day, and does this over a 30-day period, the home would use 450 kilowatthours or 450 kWh. If the cost of electricity is 5 cents per each kWh, the home would use $22.50 worth of electric energy for the 30 days or about 75 cents per day. In this example, the home uses about .63 kilowatts each hour or just over 3 cents per hour. There are 720 hours in the 30 days. This multiplied times the average cost per hour = $22.50.

Now suppose a check is made on an individual appliance, such as an electric clothes dryer. The name plate shows 20 amp at 220 volts. This equals 4,400 watts of power or 4.4 kW. If it takes 45 minutes to dry a load, what does the load cost to dry at a 5 cents per kWh rate? The 4.4 is multiplied by three-quarters of an hour which gives 3.3 kWh. This in turn is multiplied by 5 cents, the assumed cost of electricity, to yield 16.5 cents per load.

Potential Energy

Potential energy (PE) is sometimes called energy of position. It can be described best with an example. Suppose a 5-pound book rests upon a tabletop that is 3 feet above the floor. As long as the book stays still or rests on the table no work is done, but a constant force of 5 pounds is exerted upon the table legs which is what keeps the book and floor apart. It is this constant, steady force that has the potential for doing work.

If the book is pushed off the tabletop, it immediately falls to the floor. It will hit with a resounding thump, which testifies to the energy of the collision. The work done by the book was

F x D = 5 x 3 = 15 ft-lb

After the book comes to rest it has less energy than before because it is closer to the earth and has less height. It would take 15 ft-lb of work to get the book back on the table.

The work that the book did, in this case, was more or less wasted unless we wanted to make a loud noise. The energy of impact with the floor was dissipated in forcing sound waves through the air, by flapping of the pages of the book and in some temperature rise (faster molecular vibration) in the material of the book and the floor.

The work that the book did could have been harnessed. A sling could have been made and suitable cords attached and run over pulleys, so that a generator could have been turned or other objects lifted while it was falling.

An example of this type work is a grandfather clock with weights on cords to keep the pendulum swinging. This does not take a great amount of human work, and this system works effectively. The potential energy of the system was put in by human power winding the weight up.

A physical body in a position above the earth (not in orbit or weightless state) has potential energy because of the force of gravity. Each particle of the body exhibits a gravitational field, and each particle of the earth does the same. The earth has a very strong or dense field because of its large mass (great number of particles). The interaction of the gravitational field of the earth and of the body causes the force.

Gravity is constantly doing work on objects that fall, whether it is a large boulder rolling down a mountain or a raindrop falling. Gravitational field density or strength diminishes with distance by the inverse square law. But within a few miles of the earth's surface the change in this force is so small that it can be considered constant.

Kinetic Energy

Kinetic energy (KE) is sometimes called energy of movement. The natural law under which it operates can be expressed easily in mathematical form as:

$$KE = \frac{1}{2} \times M \times V^2$$

In this law the mass of an object must always be expressed as its weight divided by the acceleration due to gravity, g. The value of g is 32 ft/s^2 at the earth's surface. The velocity of the object must be given in feet per second and the weight in pounds. The answer for the amount of kinetic energy will be in foot-pounds. These units may be checked out in the law as follows:

$$KE = \frac{1}{2} \times \frac{W}{g} \times V^2 = \frac{1}{2} \times \frac{lb}{\frac{32\ ft}{s^2}} \times \left(\frac{ft}{s}\right)^2$$

$$= \frac{1}{2} \times \frac{lb}{1} \times \frac{s^2}{32\ ft} \times \frac{ft^2}{s^2} = \text{ft-lb}$$

If an object weighing 100 pounds is lifted 10 feet and put on a shelf, the object has 100 x 10 or 1,000 ft-lb of potential energy stored due to its mass and position. If the object fell to the floor it would do exactly that much work, and the floor would have to withstand or absorb that amount of energy. We see then that potential energy and kinetic energy are equal.

Dimensions

In studying energy the words length, area and volume appear frequently. In addition, the miles per gallon that vehicles get, the cubic feet of gas used and barrels of oil or tons of coal available are all familiar terms used in the popular press. In calculations about energy these terms and others will be used. Can you visualize a mile, a foot or a meter? How big is a barrel or a pound of air?

To answer these and similar questions you have to rely on your experience. Persons who have lived in the Midwest are accustomed to miles. The lands of the Midwest have been divided into square miles, and it is easy to compare from memory, other distances to these squares laid out one mile on each side. If you have bought foods, such as milk or fruit in gallon containers you can from memory, visualize the size of a gallon.

Length

When you take a point, which is dimensionless, and move it in a straight line you form a path which is called a line segment. From the point where you start to the point where you stop is called the segment. Actually the line extends both ways to infinity, and you can use as much of it as needed. What you use is called a segment. This segment, or the infinite line for that matter, has only one dimension, length.

Distances or lengths of any dimension are relative. Supposing you have measured the length of a room from one inside wall to the other and found it to be 14 feet and 3 inches. If you were not familiar with a foot length ruler, this dimension of 14 feet would not mean anything to you or to another person to whom you were describing this distance. But since both of you can mentally picture a foot ruler, you can imagine it laid down 14 times, end to end, with just 3 inches left over. The room then is compared or related to the familiar foot ruler as 14 to 1. This can be written as 14:1 as a ratio or as a fraction 14/1, indicating division where the answer is 14.

It would make no difference what length the measuring stick, in this case a foot ruler, had; the process is exactly the same. The actual length of the room would not change, just the ratio. But a ratio is dimensionless. The word foot was applied to the answer of the example to let everyone know that the room was being related to a foot ruler.

This process makes it possible for two or more persons to communicate about the size of objects without having the actual object present. Drawings or plans of large objects can be faithfully reproduced on small pieces of paper by reducing actual dimensions by a certain ratio. The ratio by which all dimensions are reduced is called the scale of the drawing. Aerial photos of several hundred square miles of the earth surface can be reduced to a map of 24 inches on each side. This ratio of reduction can be several thousand to one.

In the metric system, the meter is the basic unit of length. In the future everything will be compared to its length in multiples of 10, both larger and smaller. The meter has a physical basis. Ten million meters is the distance from the equator of the earth to either of the poles.

The following table gives the comparison of various units of length.

1 inch (in) = 2.54 cm	1 centimeter (cm) = 0.3937 in
1 foot (ft) = 30.48 cm	1 meter (m) = 39.37 in
1 mile (mi) = 1.609 km	1 kilometer (km) = 0.6214 mi
1 micron (u) = 0.001 mm	1 angstrom (A) = 10^{-8} cm
1 cm = 10 mm	1 meter = 100 cm
1 km = 1,000 m	

Area

If you take a line segment and move it sideways, you form a flat or smooth surface called a plane. This plane has two dimensions, each of which is a length and measured along two perpendicular edges of the plane. These two dimensions must be in the same units, such as feet, inches or meters. When these two dimensions are multiplied together, the area of the plane, in square units, is found. If the foot ruler happened to be the basic unit, the answer would be square feet. This can be written in abbreviated form as ft^2, because feet times feet is the same as feet squared or ft^2. In inches, the answer would be in^2 and in meters it would be m^2. Anytime you see an answer in this form (a unit with the exponent of 2) it denotes area, and you can immediately think of a flat plane of approximate dimensions to make the area. The two as an exponent denotes an object with two dimensions.

The following table gives the comparison of various units of area.

1 square inch (in^2) = 6.4516 square centimeters (cm^2)
1 square foot (ft^2) = 929 square centimeters (cm^2)
1 square foot (ft^2) = 0.0929 square meters (m^2)
1 square yard (yd^2) = 9 square feet (ft^2)
1 square yard (yd^2) = 1,296 square inches (in^2)
1 acre = 43,560 square feet (ft^2)
1 square mile (sq mi) = 640 acres

Volume

If you take the flat, smooth plane and move it straight up, keeping it level, you form an object (a box) that has three dimensions. As before, these dimensions must be in the same units. When these three are multiplied together the answer is the volume of the solid in cubic units, such as cubic inches or cubic feet. In abbreviated form this is in^3 or ft^3. Anytime you see an answer like this it means volume or a three-dimensional object.

For instance, from your experience you can imagine a cube 1 foot on each edge. The volume of this cube is 1 cubic foot or 1 ft^3. Now if you measure an object and find its volume to be 5 cubic feet, 5 ft^3, you can mentally compare the object with five cubes that are each 1 foot on a side.

The following table gives the comparison of various units of volume.

1 quart (qt) = 0.946 liter (l)
1 gallon (gal) = 231 in^3
1 cubic foot (ft^3) = 1,728 in^3
1 barrel petroleum = 42 gal
1 liter (1) = 1.057 qt
1 liter (l) = 61 in^3
1 cubic inch (in^3) = 16.39 cm^3

Time

If we kept records it might turn out that the word time is used more often in everyday conversations than any other. But when asked what the word means we find it very difficult to give a simple explanation. Time seems abstract and apart from real things. Time appears in most formulas concerning energy.

Time is used to measure the enormous distances between objects in the universe. This "yardstick" of the astronomers is the distance that light travels in one year. It is spoken of as a light year.

One of the first formulas learned in algebra is:

Distance = rate x time or D = rt

Either side of the equation may be used because distance and rate x time are equal and mean the same thing. In using the term light years the astronomer never really says anything about a physical distance but time is used in the word "years." Yet, a physical distance is implied through the equation. We are about to learn that time is a real thing and can be related only to real things. If there were no real objects in the universe there would be no such thing as time.

At the equator, the circumference of the earth is about 25,000 miles. It makes one revolution in what we call 24 hours. An object at the equator therefore travels 25,000 miles in 24 hours or about 1,000 miles each hour. In math form (from the equation above) it is:

$$\text{Velocity} = \text{rate} = \frac{\text{distance}}{\text{time}} = \frac{25{,}000 \text{ mi}}{24 \text{ h}} =$$
$$1{,}000 \text{ mi/hr (approximate)}$$

This can be divided by 60 minutes per hour to give the miles per minute.

$$\frac{1{,}000}{60} = 16.66 \text{ mi/min}$$

Dividing again by 60 the value of miles per second is:

$$\frac{16.66}{60} = 0.277 \text{ mi/s}$$

Since each mile = 5,280 feet, the miles per second can be multiplied by this value to find the feet per second an object at the equator travels.

$$\frac{5{,}280 \text{ ft}}{\text{mi}} \times \frac{.277 \text{ mi}}{\text{s}} = 1{,}463 \text{ ft/s}$$

Referring to the last equation, which gave 1,463 feet of travel for an object on the equator of the earth, we find that this is what a second of time amounts to. The second is related to an actual physical distance. The second hand on a watch would move 1 second, while this object at the equator moved 1,463 feet. Or, we may visualize the second hand of a watch as always pointing at this object.

Time then is just a ratio comparing the position of one object with the position of another. If you could throw a baseball at a velocity of 80 feet per second, it would travel the 80 feet while an object at the earth's equator was traveling 1,463 feet.

Time is relevant. While an event we are measuring or witnessing takes place, other objects in the universe are moving at regular set relationships.

Mass Versus Weight

The meaning of the word mass is usually given as the amount of matter a physical object contains. The word matter, for use here, may be thought of as the sum of the nuclei and electrons (atoms) that make up the physical object. The total number of atoms making up the object will be the same if the object is on the surface of the earth, the moon, or out in space a million miles from any other object.

Weight is entirely different but dependent upon the mass of an object. Each nucleus and electron of the atoms that make up an object exhibit a gravitational field. The gravity field of an individual atom is exceedingly small but the number of atoms is enormous and all the fields are summed together; so that an object the size of the earth exhibits an effective total field. The gravitational fields of two separate objects interact and cause an attraction between the two objects. The objects will move toward each other and come completely together, unless kept apart by a force opposing the attraction and equal to it. It is this force that is called weight.

The attractive force of an object is greater on the surface of the earth than it is for that same object on the surface of the moon. This is because the earth's mass is greater and has a stronger or denser gravitational field to interact with the object than that of the moon. The force required to keep the object separated from the surface of the earth is greater than required on the moon. The mass of the earth and moon is different, but the mass of the object is the same in each case.

The mass of an object is directly related to inertia. Inertia is that property of an object in motion that requires it to continue that motion unless an outside force causes it to change. Inertia also can be expressed as that property of an object that keeps it at rest unless an outside force moves it. The attribute of inertia is the same for a given mass (or group of atoms) anywhere in the universe. It depends solely on the number of atoms making up the mass of the object.

Combustion

Technically, the word combustion means any chemical reaction giving off heat and light. Our most common acquaintance with combustion is a fire that produces a flame. Combustion occurs when oxygen unites with a fuel rapidly enough to produce heat, light or both. Oxygen can combine with other substances so slowly that no light and no heat are apparent. Rusting of iron or steel is one example. This slow process is called oxidation, rather than burning or combustion.

Extremely rapid rates of combustion are called explosions, such as those produced by dynamite or gunpowder. Sometimes this is the desired result. Many times a slower rate or even a variable rate is needed.

Three things are needed for combustion to occur. First, there must be a fuel that will break down or crack and unite with oxygen; second, there must be a supply of oxygen in the presence of the fuel. This is usually supplied by the atmosphere but it can be mixed in with the fuel as in gunpowder, dynamite or in rockets carried as liquid oxygen. The fuel and the air must be in vapor or gas form and mixed uniformly in the right ratio. The third condition is that a part of this mixture must be raised to the kindling temperature, using a spark or match to start uniting the fuel atoms with the oxygen. When this happens heat is given off. Some of this heat raises adjacent fuel-oxygen mixture to the kindling temperature; thus, the burning progresses on to new fuel. Some of the heat may be needed to vaporize the fuel, as would be the case with solid fuels, such as wood, coal, gunpowder or candles, and with liquid fuels, such as propane, gasoline, diesel or oil. Heat left over can be used for useful work or in the heating of rooms.

Temperature

It would be hard to find another word that is used as much as temperature. We use this word in talking about the weather. We complain that our cold drinks are not cold enough or that our hot drinks have cooled. Many of us hesitate to go into a swimming pool because the water is too cold. In all these examples we are referring to the temperature of things as they exist, at that moment, and of the temperature we want them to be. What we are actually referring to is the level of heat in objects. The level of heat in cold coffee for instance, is too low for our liking.

The level of heat is really the amount of kinetic energy stored in the molecules of the objects with which we are concerned. We are talking now about something that we can picture to help describe temperature. Any moving object has kinetic energy. In math form it is:

$$KE = \frac{1}{2} \times M \times V^2$$

Consider a molecule of air. The atmosphere is made up of mostly nitrogen (N_2) and oxygen (O_2). A molecule of either one is about the same mass (they are side by side in the periodic table) but is extremely small compared to a bullet. All molecules in the atmosphere are in a state of vibration. Each molecule vibrates many times per second, maybe billions of times. In doing so it strikes its neighbor and causes it to continue its vibrating motion. The average velocity of the molecule at sea level is about 1,100 mph. This would be 1,613 feet per second. Even at this extremely small mass, each molecule exhibits an effective amount of kinetic energy because of its velocity (similar to a rifle bullet). One molecule of air by itself would be insignificant. But there is a vast number in 1 cubic foot of the atmosphere at sea level. All these together can exhibit a significant amount of energy.

To measure the effect of this vibration or the kinetic energy exhibited, a thermometer is used. The thermometer is made of mercury (Hg) inside a glass tube with a small bulb on the end. If this bulb is immersed in the 1 cubic foot of atmospheric air and left for a short time the vibrations of the air molecules against the glass cause the molecules in the glass to reach nearly the same frequency of vibration, and the glass in turn causes the molecules in the mercury to vibrate.

An increase in vibration rate causes each molecule of a material, whether air, glass or mercury, to take up more space. Likewise, they would take up less volume if the vibration rate slowed down. The mercury in the bulb will take up more space if the air vibration is greater, causing the glass and the mercury to vibrate faster and increase in volume. When the mercury in the bulb expands, it forces its way farther up the small tube, thus increasing the length of this column. This increase in length to a new height becomes the temperature reading (in numbers) of the 1 cubic foot of air.

One additional fact should be described to help complete the picture of temperature or level of heat. We will use water as an example. Imagine a small metal tube, one-quarter inch in diameter and 200 feet long. Stand this tube on end and fill it with water. Now imagine a large dam across a river impounding the water to a depth of 200 feet and backing water up the river for 150 miles. The 1/4-inch diameter tube, 200 feet long, contains about one-half gallon of water weighing about 4 1/4 pounds. The lake contains several hundred billion gallons. Even with this great contrast in volume the two illustrations have one thing in common. The pressure at the bottom of the tube is exactly the same as the pressure at the bottom of the lake, about 86 pounds per square inch.

It is true that the water could run out of the bottom of the tube and empty in a very short time. It would take years for the lake to empty out this way. In fact large diameter tubes, maybe 4 to 6 feet across, can be put in the dam to direct the outflow of water against turbines to generate electricity.

It is evident that the total stored potential energy is vastly different in the two illustrations, even though the pressure is exactly the same. The pressure in the water examples can be thought of in a similar way to temperature. It told nothing of the total amount of energy available in each of the two illustrations. The temperature tells about the velocity of the molecules, and the total weight tells the mass or quantity of molecules. These two values have to be multiplied to obtain the total kinetic energy.

In the very upper regions of the atmosphere the molecules of air are a great distance apart. Some of them may reach extremely high velocities. The average velocity is much higher than at the earth's surface. As a result, the kinetic energy of an individual molecule is much higher; therefore, the temperature is calculated to be much higher in these regions than at the surface running as high as 1,000°F or more. The total kinetic energy is not very great because of low density of the atmosphere.

Temperature may be thought of as one body of substance being able to transfer heat to another body. The one with the highest temperature will always send heat to a body of lower temperature. The greater the difference the faster the heat is moved. This is a fundamental law of thermodynamics. Thus, a thin metal cup containing water at 200°F will send heat into a bathtub holding 20 gallons of water at 100°F if it is set into it. In a similar fashion, the 200-foot tube of water will send water into the lake if the level of water in it is raised any amount above that of the lake.

The effective temperature of a body is the average, kinetic energy of all the molecules of the body. For example, imagine a homogeneous metal sphere sitting on a cake of ice. A torch applies heat to the top of this sphere until a small spot at the top becomes red hot. This is a temperature of about 1,200°C. The ice is at 0°C; therefore the surface of the metal sphere in contact with the ice would be very near 0°C. Somewhere in between the top and bottom of the sphere, about halfway, the temperature of the metal should be about 600°C. Heat would flow through the steel ball from the top to the bottom and hasten the melting of the ice. But the temperature at the center would remain constant. This would be the steady state of the system until the torch ran out of fuel or all the ice melted.

If the ball could be placed in some medium that was at 600°C, such as an oven, the hot spot would cool off and the cold side would heat up until all the volume of the sphere was at 600°C.

A thermometer used to measure temperature may have two types of indicator markings or scales, usually one on either side of the column of mercury. They can be easily compared. The Fahrenheit scale marks the freezing point of water at 32 degrees and the boiling point at 212 degrees. The centigrade scale marks the freezing point of water at 0 degrees and the boiling point at 100 degrees. We have used the Fahrenheit scale so much, in everyday life, that we are more used to it. The level of heat measured is the same regardless of the scale used.

Absolute Zero

We have seen that heat manifests itself in vibration of the molecules of a substance. If a substance is cooled until all vibration ceases, the molecules sit absolutely still, adjacent to each other. Molecules have other motions besides lateral vibration. They may rotate about any one or all of three axes at one time. Until this rotation ceases all kinetic energy or heat has not been removed from the substance.

When all activity has been removed, absolute zero has been reached. It is considered to be -273°C or -459.4°F. Absolute zero is similar to the speed of light. The closer it is approached in actual practice, the more difficult it is to reduce the temperature farther. It has not been approached closer than about 1 or 2°F.

Heat

The word heat also is frequently used in everyday conversations. Many times the words heat and temperature are used interchangeably. They are so closely related that it's easy to make a mistake. Referring to the example of the cup and tub used in describing temperature, remember that the cup of water had a temperature of 200°F while the tub of water was at 100°F. This means that the molecules of water in the cup were moving much faster than those in the tub. If we summed all the kinetic energy of each of the molecules in the cup, we would determine the total foot-pounds of kinetic energy the cup contained.

In the same fashion we could sum up all the kinetic energy in the tub in foot-pounds. Probably the tub would contain much more kinetic energy or more total foot-pounds because of its greater mass. We know from experience that this is true, and we simply say that the tub possesses more heat than the cup of water. If the cup of water were accidently spilled on bare skin a scald or burn would result. Yet the whole tub of water will not damage the skin even though it contains much more total heat.

Tiny drops of grease may pop out of a skillet onto a bare arm causing very tiny blisters, resulting in minor discomfort. In contrast a deep pan of oil at the same temperature, if accidently spilled on bare skin would be catastrophic.

The heat from the tiny drops of grease was transferred into the skin of the arm because the drop was at a higher temperature. Its molecules were vibrating at a much higher rate than those of the skin. The molecules in the small area of the skin, in contact with the grease, speeded up drastically, killing the living cells; but, the grease molecules by that time were slowed down so that their kinetic energy was equal to the kinetic energy of the skin, and no more damage was done.

The large pot of oil at the same high temperature contained a much greater quantity of heat, and the skin could not absorb all the vibrations without severe damage to a large area of skin. Thus, we see that temperature depends only on the speed of the molecules, while heat depends upon both the speed and the number or mass of molecules involved.

Extracting Work from Heat

Because heat is kinetic energy or a measure of the total vibrations of the molecules of a body in foot-pounds, work can be extracted from heat. In other words, mechanical movement can be obtained from heat.

An example of this is a steam engine. Some kind of fuel is burned near a container of water. The molecules of the gas in the flame vibrate at a very high rate. This flame touches the metal pipes or containers and transfers heat to the molecules in the metal, speeding up the molecules. The metal becomes hotter than the water or the metal molecules vibrate faster than those in the water so the metal transfers heat to the water.

If the flame temperature is high enough to get the metal hot so as to raise the temperature, or rate of vibrations of the water, some of the molecules in the water will speed up enough to jump out of the liquid. If this continues at a fast enough rate, the atmosphere above the water will become saturated with high speed water molecules, and we will have steam building up pressure. There is quite a distance between these molecules compared to those in liquid water; the speed of the steam molecules is much higher than those in the liquid. Each molecule of steam has more kinetic energy than those molecules in the water, so fewer of them contain the same amount of heat or kinetic energy.

High pressure steam can be led through pipes to cylinders or turbines to push a piston or impinge against the blades of the turbine in order to produce actual mechanical work. This work can be harnessed by connecting rods between cylinders and wheels or, in the case of a turbine, to gears and wheels.

We have thus successfully completed the large step from stored chemical energy in fossil fuel to useful mechanical motion. Note that it was all done in a series of steps, each consisting of the actual movement of bodies. The bodies of the flame consisted of fast-moving molecules of a hydrocarbon fuel, say propane, uniting with oxygen (see the discussion of combustion on page 10). The chemical formula for this reaction is:

$$C_3H_8 + 5O_2 \rightarrow 4H_2O + 3CO_2$$

On the right hand side, the water and carbon dioxide molecules in the flame are excited or vibrating at extremely high speed. They caused the molecules in the metal water container to speed up. There were billions of molecules in the fuel, each having billions upon billions of vibrations. Not all these molecules, however, were able to apply their kinetic energy toward the metal. Some bounced sideways out of the flame and were lost, thus, not giving any further force toward our useful end. It is the job of mechanical engineers to design heat transfer systems to capture as much of the kinetic energy of the flame as possible so it can be transferred to the containers; and, to design the container so it transfers as much kinetic energy as possible to the water, and so forth.

At the present time, engineers are able to produce about 40 percent overall efficiency in large steam power plants, and a little less in movable engines because of sacrifices necessary for mobility.

The important thing to realize is that chemical energy (heat) is harnessed. In fact, the word harness is probably the key word throughout this Energy Resource Series. There are many sources of energy. The big problem is getting the energy effectively harnessed to do useful, controlled work.

Notice that the chemical energy in the flame consisted of many billions of extremely small movements we called vibrations. You can think of them as many small levers moving very fast over small distances, much too small and fast to directly hook onto. By changing ultimately to fewer and slower molecules of water in the steam, we get all these little fast-moving levers to move a piston and one extremely large lever, the crank shaft, on a wheel that we could hook our load onto.

Every time a change or step is necessary to get from the chemical energy heat source to the crank shaft, some efficiency is lost. In fact, if enough changes are made, all the energy will be taken up in these changes alone and none left for the final lever. A system like this has zero efficiency or 100 percent loss and results in no useful work. This is like having a transmission on a car or tractor so big, that in order to reduce the engine speed to the driving wheels and attempt to increase the torque at these wheels, the transmission is all the engine can turn. Therefore, one way a researcher can attempt to increase the overall efficiency of an energy conversion system is to eliminate some steps, if possible.

It is also important to note that in a heat engine system like we have described, the temperature of the source immediately preceding a change or transfer must be at a higher level than in the body the heat is transferred to. Thus, the flame must be at a higher temperature than the metal container, and the container must be at a higher temperature than the water. The greater the difference between original source and the adjacent medium, the faster the heat will flow.

Measurement of Heat

The measurement of heat is usually given in one of two systems, the British or metric system. In either system, a quantity of heat energy, or the kinetic energy of the vibrations of the molecules, is used. In the British system, the basic unit is the amount or quantity of energy required to raise the temperature of one pound of water one degree on the Fahrenheit scale. This amount of heat is called one British thermal unit (Btu). In the metric system the basic unit is the amount or quantity of energy required to raise the temperature of one gram of water one degree on the centigrade scale. This amount of heat is called one calorie.

The heat energy that a fuel will produce by combustion is found by use of a calorimeter. This apparatus is a highly insulated vessel containing an inner combustion chamber surrounded by water. Into the chamber a measured weight of fuel is placed along with ample oxygen. Usually a spark is used to ignite the fuel-oxygen mixtures. The heat energy produced by the combustion will in a short time heat the chamber wall and then the surrounding water. Insulation surrounding the water reduces the escape of heat to the outside. The rise in the temperature of the known weight of water and known weight of fuel gives the amount of heat produced by any quantity of that fuel.

Heat Translation

In the description of heat, an example was given of the kinetic energy in fossil fuels moving from the high temperature flame into water, forming steam that moved a lever arm and did mechanical work. The description of the kinetic energy of the molecules of the material was carried through, step by step. This is heat transfer, that is, translation or movement. In general, energy in the form of heat can be translated in three ways: by conduction, convection and radiation.

Conduction

When two physical objects at different temperatures touch, heat will move or flow from the object with the higher temperature to the one with a lower temperature. This is a natural fact known as the second fundamental law of thermodynamics. This is done as described in the steam engine example. The kinetic energy of the faster vibrating molecules in the higher temperature object causes the slower vibrating molecules in the lower temperature object to speed up. As a result, the faster ones lose some of their energy, and the slower ones gain energy. This continues until the energy level or temperature of the two objects is the same.

The objects do not have to be solids. One could be solid and the other a gas or liquid. An egg in boiling water cooks because the kinetic energy of the rapidly vibrating molecules of water striking the egg shell is transferred to the inside of the egg.

Convection

Convection means to convey or carry. This process is usually thought of in terms of gases and liquids. In a home heating system, a furnace can heat air at some central point. A fan can move this heated air into several rooms forcing the colder air to return to the furnace and be heated in a continuous cycle. In this example air was the medium to convey the heat.

Water also can be used. It is heated in a standard hot water heater and pumped to rooms through insulated pipes. Usually finned pipe is used to offer more contact surface with the room air, thus, hastening heating. Usually the finned pipe is near the floor against an outside wall. The air that touches the hot pipe becomes excited and less dense, therefore, more dense air moves in and forces the newly heated air upward. Thus, there is circulation of warmed air rising and moving across the upper region of the room and gradually cooling as it gives up the newly acquired kinetic energy from the pipe. As it cools and becomes more dense, it settles toward the pipe and continues the cycle. The objects in the room including people are becoming warmer as the warm air touches them and transfers heat to them. This is a convection cycle.

Convection heating continually takes place in the atmosphere. Air in contact with hot desert sand becomes less dense and rises. Air in contact with frozen northern land becomes less dense and stays low. It gradually moves out sideways and can start a cold front moving across the country.

Radiation

In both the conduction and convection processes, heat is transferred from one medium to another by the vibrating molecules. But heat energy can travel through space where there is no medium. A person can feel the heat of the sun that is 93 million miles away across space. The heat from a light bulb or electric heating coils can be felt, yet you do not actually touch them. This phenomenon is more difficult to grasp because it goes right to the heart of matter. Heat that travels through space, as well as ultraviolet light, X-rays, radio, television and radar waves all fall in the general category called electromagnetic radiation. In fact, gravity itself might be included in this category along with magnetic and electric (positive and negative charges) fields.

Electromagnetic radiation consists of exceedingly small, practically massless particles called photons. Excited atoms can give off many of these photons, or atoms can receive them and become excited. Photons travel straight away from the excited atoms that emitted them until they strike another atom and are absorbed by having excited it.

Imagine the electric light filament that is illuminating this page you are reading. The filament wire is white hot, about 3,000°C. The atoms are in an extreme state of vibration. The electrons that orbit these atoms are boosted to a higher orbital distance because of the extra input of energy. Some atoms slow down in cooler regions of the wire, and the electrons drop into a closer orbit giving up the energy put in. It is this quantity of energy given up by the falling electron that is known as the photon. The photon may be emitted straight toward this page along with trillions and trillions of others. This stream of photons is called radiation.

Electrons falling from different orbits give off different sized photons, but they all travel at the same speed forward—the speed of light. While they travel they vibrate perpendicular to the path of travel. Different sized photons vibrate at different rates. Some of these vibrations may be such that the rods and cones of the retina of the eye are tuned to them or are sympathetic to them. This would be the visible light portion of the spectrum.

Of the photons from the electric light filament that traveled to this page, some hit the dark ink of the print and were absorbed into those atoms raising their excited level and temperature; while others struck the white part and were reflected to the eye. Here they passed through the pupil and were focused on the retina. The vibrations of these photons stimulated the rods or cones and transmitted electrical impulses to the brain cells. In this fashion sight is made possible with light.

Thus, energy has been transferred across space. The air molecules between the light bulb and eye had nothing to do with it.

The rise in activity of the cones and rods also causes a rise in their temperature, but it is too infinitesimal to be measured. However, the electric signal they send to the brain can be measured by sensitive nerve conduction instruments.

Photon vibration frequencies just below visible light are the infrared band. This band is known as the heat portion of the spectrum. If all the vibrations of the photons emitted from a source were in this range, the eye could not see them, and radio receivers would not be sensitive to them. But the nerve endings in the skin would detect them and send this information to the brain. This is the way we feel heat.

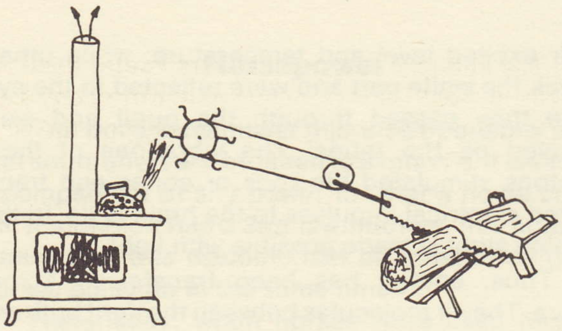
Radiation in the infrared frequency range is given off strongly by warm to hot objects. At temperatures of 1,000°C this approaches a maximum.

Harnessing Energy

The word harness will appear quite often in written and verbal conversations concerning energy. It is important that when we see or hear it in this context, we can quickly understand what is being conveyed.

We humans use energy in three different ways: as heat and light, and as a means of forcing some mechanical contrivance to move. Some people may want to include chemical forms but here the electrons are pushing and being pushed or forced to move.

Energy in many forms can be available to do these three things. Wood or other dry fuel, as an example, can be burned to furnish heat. If heat is what we want, this may be the answer for our needs. But if you want to fell a tree and cut it up into small pieces for the stove, how do you connect the heat from burning wood to an axe or saw? That's what the word harness means—to connect mechanically. The following figure illustrates a method of harnessing the heat from burning wood to saw wood.



An animated description of energy transition from one form to another to obtain a desired action. Here wood is burned to make steam to drive the saw. The saw cuts the wood which in turn can be burned.

At the dawn of human history, the first form of a harness was probably the handle on a stone which provided much greater leverage for hitting things. Then came handles on knives and spears. Early man probably learned how to harness his own body to a small load with shoulder boards, how to carry baskets on his head, or drag small tree limbs as lean-to sleds. Then man discovered that with various physical hookups animals could be used to greatly multiply his efforts.

In pioneer days the horse was the main source of power to move objects. Man devised a system of ropes and straps to attach the body of the horse to a load, so that it could either carry it or pull it. In the pioneer cabins heat was the big need to survive the cold winters. This was provided by burning wood in a stove or fireplace. A small side benefit was some light from the flame. This light was only enough for gross-type work. It certainly was not adequate for the fine arts of reading, sewing, etc. When nighttime came most work came to a halt. This heat also served to cook all meals. This worked well in the winter but the excess heat was very undesirable in the summer.

The physical work that required movement of objects, such as clothes washing, butter churning and meat and vegetable cutting was done by hand. In the modern kitchen a closely controlled natural gas flame or electric heating element is used for cooking. Other heaters in the cooking process are the electric toasters, electric coffee makers, ovens and other assorted appliances. Light is provided several hundred fold, compared to the early cabins, by incandescent or fluorescent electric lights. Mechanical movement appliances include knives, can openers, meat grinders, blenders, slicers, mixers, clocks (timers that move switches), dishwashers, disposals, compactors, knife sharpeners, ice crushers, vent fans and refrigerators. This list is long, and people of today are quite familiar with all these objects.

In all of these objects one of three things was wanted from the source of energy, either heat, light or a physical movement. The only types of energy in the modern kitchen mentioned here were natural gas and electricity. The gas provided only heat, while electricity performed a variety of jobs. In each case the origin of the energy was a type of fossil fuel. In the case of natural gas the actual material is brought to the house by a complex system of pipes and pumps where it is burned to furnish heat.

The electricity begins with some fossil fuel, gas, oil or coal burning to form steam. This steam turns a turbine that turns a generator in some far-off power plant. The power plant then pumps the electric current via wires into the house.

Electricity is a very convenient and desired form of energy, because it can do all the various jobs wanted, such as heating, lighting and mechanical movement. But the fact is that to get it, we must go through several different forms or changes of energy resulting in inefficiency. The first change is combustion or burning to get high pressure steam. Then we get mechanical motion (the rotating turbine and generator), then electricity with losses in the transformers and transmission lines in the form of heat. The final change is back to heat and light and mechanical motion in the house. To get the convenience we want we must suffer the sacrifice of inefficient changing from one form of energy to another. Usually the closer to the original form we can use the fuel, the more efficient it will be, such as heating with gas, wood or coal. This problem then is one of harnessing. It is actually an engineering problem. An engineer must look at all phases of the harness system and arrive at one that will be most efficient overall.

It is more efficient to heat homes with individual coal furnaces than to take the coal to a power plant, and then heat the home with an electric furnace. But the large distribution system, probably trucks, required to get the coal to each home proves to be less efficient than the electric distribution system. It may prove simpler to achieve cleaner burning at one large power plant than at many individual houses.

In the primitive cabin there were windows and doors. It was a long time before glass was available to cover the windows. Usually they were covered with animal skin. Suppose that on a clear and mild winter day one of these windows was uncovered and the sun shone through and hit the wooden floor.

If the window was about 2 feet on each side, its area would be 4 ft^2. On a clear day 300 Btu per hour of energy may strike each ft^2 of the earth's surface. Through this window would then come 1,200 Btu each hour.

Theoretically 2,600 Btu = 1 hp. Setting up a proportion we can find out how much horsepower (X) comes through this window as follows:

$$\frac{2{,}600 \text{ Btu}}{1 \text{ hp}} = \frac{1{,}200 \text{ Btu per hour}}{X}$$

By cross multiplying:

$$X \times 2{,}600 \text{ Btu} = 1 \text{ hp} \times 1{,}200 \text{ Btu per hour} = 1 \text{ hp} \times \frac{1{,}200 \text{ Btu}}{h}$$

$$X = \frac{1{,}200 \text{ Btu}}{h} \times \frac{1 \text{ hp}}{2{,}600 \text{ Btu}} = .46 \text{ hp per hour}$$

This value of nearly one-half horsepower each hour is theoretical and will have to be multiplied by all the efficiencies when changing from one form of energy to another. These changes will probably cut the output by one-half. But think of a 1/4-hp electric motor in a cabin. This could run a washing machine or a refrigerator and be hooked up to many other devices, such as the butter churn. Of course, we must remember that this is **only** when the sun shines. This amount of sunlight would not be a large factor in the heat needed to warm the cabin on a severe winter day. At a time like this the cabin might need 25,000 to 50,000 Btu per hour.

But the problem here is how to harness this potential energy in the form we want. This is where a trained engineer must devise methods using obtainable physical material to change the sunlight into mechanical energy.

The sunlight automatically translates itself into one form, heat. On a clear and mild winter day a dog or cat in the cabin would instinctively find the warm spot on the floor. The sunlight then would warm its body and it would stay there all day, moving only to keep up with the sun's movement across the floor. It is a vastly different story though when we want to harness sunlight into mechanical movement with a force.

In a way the pioneers did just that. A swift-running stream with a waterfall was the potential for a waterwheel. Indirectly the sun powers the waterwheel. The heat from the sun evaporates water from the earth's surface where it is carried as vapor on warm, rising currents of air (this energy comes from the sun also) until at great heights it cools, condenses, and forms droplets dense enough to fall through the atmosphere, long distances from where it originally evaporated. The rainwater flowing through rivers and streams by the force of gravity moves across the earth's surface and finally turns the waterwheel. Today's big dams and water turbines are improved, larger versions of the first waterwheels. An important point is that they are operating on sun power and do not pollute anything.

One giant problem exists though. Engineers tell us that the amount of water that could be stored in present and proposed lakes will furnish only a small fraction of what is wanted by the people in the United States. But this source helps. It keeps the other types of fuel-burning plants from being so big. There is a lot of activity in the solar energy area now seeking new and improved ways to harness this vast and lasting source of energy. Harnessing sunlight and other energy sources has tremendous potential.

Questions

To stimulate thought and greater understanding, answer these questions with the best word(s) to make a true statement. Refer to the material when necessary.

1. What does the word harness mean as it used in this book? ______________________________

2. Why is piping natural gas to homes and burning it for heat a more efficient system than burning it in a steam power plant and using the electricity for heat? ______________________________

3. Can we use coal the same way as in number 2? (Yes or No) ________

4. Is there air pollution from hydroelectric power plants? (Yes or No) ________

5. What is a seemingly unsolvable problem with hydroelectric power? ______________________________

6. What was probably the first human effort of harnessing to multiply effort? ______________________________

7. Give the steps in the complete circuit of energy that drive a waterwheel. ______________________________

8. Will the mass of an object on earth be the same on the planet Jupiter? (Yes or No) ________

9. Can any movement of an object take place without expending energy? (Yes or No) ________

10. Any output of energy is at the expense of mass. (True or False) ________

11. A 25-pound object moved to a new location has the same work done on it regardless of the time required or the path taken. (True or False) ________

12. Work and power are actually the same thing. (True or False) ________

13. If an electric hairdryer uses current of 3.5 amp on a 110 volt circuit, what does it cost to operate for 1.5 hours at an electric rate of 7 cents per kWh? ________

14. An 80-gallon electric water heater uses a current of 25 amp on a 220 volt circuit whenever the thermostat is on. It is on an average of six hours each day. What is the cost per year of operating this appliance on a special off peak rate of 2 cents per kWh? ________

15. Potential energy and kinetic energy are actually the same. (True or False) ________

16. A straight line has two dimensions. (True or False) ________

17. During the combustion process the hydrocarbon fuel molecules break up and reunite with oxygen to form carbon dioxide and water. (True or False) ________

18. Any kind of hydrocarbon fuel must be in vapor form before it can burn. (True or False) ________

19. The cold from an ice cube held in a bare palm soaks into the hand. (True or False) ___________

20. A cup of water can contain as much heat as a bathtub full of water. (True or False) ___________

21. Heat can move from one place to another in either of three forms. Name them. ____________________
____

22. The temperature of any substance whether a gas, liquid or a solid is manifested by the kinetic energy of its molecules. (True or False) ___________

23. Modern refrigerators must reach absolute zero temperature in their freezer compartments. (True or False) ___________

24. What is probably the most important aspect of the subject matter area of energy? (It can be summed up in one word.) __________________

Answers

1. to use as heat or to move objects
2. Efficiency is lowered by changing forms.
3. no (We can't distribute coal as easily.)
4. no
5. Natural places for dams are limited.
6. handles on stones
7. evaporation, condensation, rain, rivers and dams
8. yes (Mass stays the same, weight changes.)
9. no
10. T
11. T
12. F
13. 4¢
14. $240.90
15. T
16. F
17. T
18. T
19. F
20. T
21. radiation, conduction, convection
22. T
23. F
24. harnessing

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